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Global Precipitation Measurement Project

(GPM)

Core Spacecraft

Propellant Tank

Specification

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

CM FOREWORD

This document is a Global Precipitation Measurement Project controlled document. Changes to this document require prior approval of the GPM Project CCB Chairperson. Proposed changes shall be submitted to the GPM Project Configuration Management Office (CMO), along with supportive material justifying the proposed change.

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CHANGE RECORD PAGE

CCR #	CCR DATE	MOD NO.	MOD DATE	Description	Section Affected
45	9/21/07	NA	NA	Baseline for RFI	All
49	1/10/08	NA	NA	Revision A for RFP	All

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List of TBDs

Item No.	Location	Summary	Ind./Org.	Due Date
TBD1 Closed	1.4.4	"GPM Mechanical Systems Specification" GPM Core Observatory Structural/Mechanical Subsystem Performance Requirement Specification GPM 422-06-01-07-001		Closed 12/11/07
TBD2 DELETED	1.4.4	GPM Propulsion System Envelope Drawing Resolution: Removed from 1.4.4. This will be part of subsystem spec		REMOVED 11/30/07
TBD3	1.4.4	GPM Transportation Plan (or a launch site specification with transport loads). Document number not assigned and document not drafted.		
TBD4	3.2.4	Propellant line volume downstream of the latch valves cannot be calculated until manifold is designed.		
TBD5	2.17.2	GPM 422-06-01-002 "GPM Core Spacecraft Mechanical Environmental Loads and Test Requirements Document", Document not yet written		

List of TBRs

Item No.	Location	Summary	Ind./Org.	Due Date
TBR1	2.17.2	Loads to be reviewed and updated periodically		
TBR2	Table 10	Particulate Cleanliness Specification		
TBR3	3.2.1.4	S/C dry and wet mass range		

1 SCOPE

This specification defines the physical characteristics, performance requirements, operational environments, safety and quality assurance requirements for the Global Precipitation Measurement (GPM) Propulsion Subsystem propellant tank. The GPM Propulsion Subsystem will use a single propellant tank. The tank will hold high purity hydrazine monopropellant. The tank will have a surface tension propellant management device (PMD) to ensure gas free propellant delivery during the mission. Positive expulsion devices such as diaphragms and bladders are not covered by this specification. The term “tank” shall be defined as the pressure shell, PMD, mounting skirt, inlet and outlet tubes and fittings that make up the complete propellant tank assembly.

NASA Procedural Requirements 8715.6, NASA-STD-8719.14, and NASA Safety Standard 1740.14 provide guidelines for the safe disposal of spacecraft that have completed their missions. In order to achieve safe disposal GPM has chosen to design its spacecraft to demise upon entering the atmosphere. For GPM, titanium and steel tanks of any thickness (including overwrapped) have been found by analysis to survive reentry and cause a significant amount of debris. The GPM tank will consist of an aluminum liner overwrapped with composite material. This configuration specified in this document has been shown by analysis to demise upon entering the atmosphere.

1.1 IDENTIFICATION

GPM 422-06-01-11-002; Core Spacecraft Propulsion Subsystem Propellant Tank Specification.

1.2 DEFINITIONS, GLOSSARY AND ACRONYMS

ACS	Attitude Control Subsystem
BOL	Beginning of Life
CG	Center of Gravity
CLA	Coupled Loads Analysis
CM	Center of Mass
EOL	End-Of-Life
GEVS	General Environmental Verification Specification
GMI	GPM Microwave Instrument
GPM	Global Precipitation Measurement
GSFC	Goddard Space Flight Center
ICD	Interface Control Drawing or Document
JAXA	Japan Aerospace Exploration Agency
MAR	Mission Assurance Requirements
MDP	Maximum Design Pressure
MGSE	Mechanical Ground Support Equipment
MICD	Mechanical Interface Control Drawing
NASA	National Aeronautics and Space Administration
PED	Positive Expulsion Device (diaphragm or bladder)
PMD	Propellant Management Device (surface tension type)
RPM	Revolutions Per Minute
S/C	Spacecraft
sccs	Standard cubic centimeters per second

SPL	Sound Pressure Level
TBD	To Be Determined
TBR	To Be Reviewed

1.3 CONVERSIONS

temperature: C = (F-32) / 1.8

length: inch * 25.40 = mm

mass: lbm * 2.2046 = kg

volume: cubic inch / 61020 = cubic meter, cubic inch * 16.387 = cubic centimeter (cc)

pressure: psi * .006895 = MPa, NOTE: Metric pressure units shall be interpreted as absolute pressure unless specifically modified using words such as “gauge” or “differential”

force: lbf * 4.448 = N

hydrazine density = 1.01260 g/cc at 15°C, 1.00815 g/cc at 20°C, 0.98098 g/cc at 50°C

1.4 APPLICABLE DOCUMENTS

The following list represents all documents which will govern the design, construction, and testing of the tank. If no revision or date is specified for the document, the latest issue at the time of contract release shall apply. In case of conflict between the requirements of these documents and the requirements of this specification, the requirements of this specification shall apply.

1.4.1 MILITARY DOCUMENTS

AFSPCMAN 91-710v3	Air Force Space Command Manual 91-710, volume 3, Range Safety User Requirements Manual, Volume 3 – Launch Vehicles, Payloads, and Ground Support Systems Requirements (replaces EWR 127-1)
MIL-HDBK-17B	Plastics for Flight and Aerospace Vehicles
MIL-P-26536	Propellant, Hydrazine, High Purity
MIL-PRF-27401	Propellant, Nitrogen, Pressurizing Agent
MIL-PRF-27407B	Propellant, Helium, Pressurizing Agent
MIL-PRF-27415A	Propellant Pressurization Agent, Argon
MIL-STD-130L	Identification Marking of U.S. Military Property
MIL-STD-2154	Inspection, Ultrasonic, Wrought Metals, Process For
MIL-STD-453C	Inspection, Radiographic
MIL-STD-810F	Environmental Test Method
MIL-STD-889B	Dissimilar Metals
SMC-TR-04-17	Test Requirements for Launch, Upper-Stage, and Space Vehicles
MIL-STD-45662A	Calibration System Requirements
MIL-W-46132	Welding, Fusion, Electron Beam, Process for
45th Space Wing Policy Letter, 23 NOV 1993	Interim Safety Requirements for Design, Test, and Ground Processing of Flight Graphite Epoxy (Gr/EP) Composite Overwrapped Pressure Vessels (COPVs) at the Kennedy Space Center (KSC), Cape Canaveral Air Force Station (CCAFS), and Vandenberg Air Force Base (VAFB)

1.4.2 FEDERAL DOCUMENTS

TT-I-735	Isopropyl Alcohol
DOT/FAA/AR-MMPDS-02	Metallic Materials Properties Development and Standardization (MMPDS)

1.4.3 NASA DOCUMENTS

GSFC-S-313-009	Fluorescent Penetrant Test Method Requirements and Guidelines
597-WI-8072.1.3	Wettable Aluminum 6061 Treatment Process

1.4.4 GPM DOCUMENTS

Note: these documents will be provided upon request.

422-40-01-004	GPM Core Spacecraft Mission Assurance Requirements
GPM 422-06-01-11-001	GPM Core Spacecraft Propulsion Subsystem Specification
GPM 422-06-01-07-001	GPM Core Observatory Structural/Mechanical Subsystem Performance Requirement Specification
GPM 422-40-03-100	GPM Core Observatory to H-IIA Interface Requirements Document
GPM 422-06-01-002	GPM Core Spacecraft Mechanical Environmental Loads and Test Requirements Document
GD 2085095	MICD, Propellant Tank, GPM
GPM 20-TBD3	GPM Transportation Plan

1.4.5 JAXA DOCUMENTS

JMR-002A	Launch Vehicle Payload Safety Standard (JAXA)
JERG-0-001	Technical Standard for High-Pressure Gas Equipment for Space Use (JAXA) (April 1, 2004)

1.4.6 OTHER DOCUMENTS

ANSI/AIAA S-080-1998	Space Systems – Metallic Pressure Vessels, Pressurized Structures, and Pressure Components
ANSI/AIAA S-081A-2006	Space Systems – Composite Overwrapped Pressure Vessels (COPVs)
ASTM D1193-06	Standard Specification for Reagent Water
ASTM E595	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
AMS-QQ-A-250/11	Aluminum 6061-T6 Alloy Sheet & Plate, Aircraft Quality
IEST-STD-CC1246D	Product Cleanliness Levels and Contamination Control Program

1.5 SPACECRAFT PROPULSION CONFIGURATION

The figure 1a and figure 1b below are provided for preliminary design only and are subject to change. GPM spacecraft coordinates are used in these figures. The Z axis points toward the earth and the X axis begins at the separation plane and points toward the front end of the spacecraft.

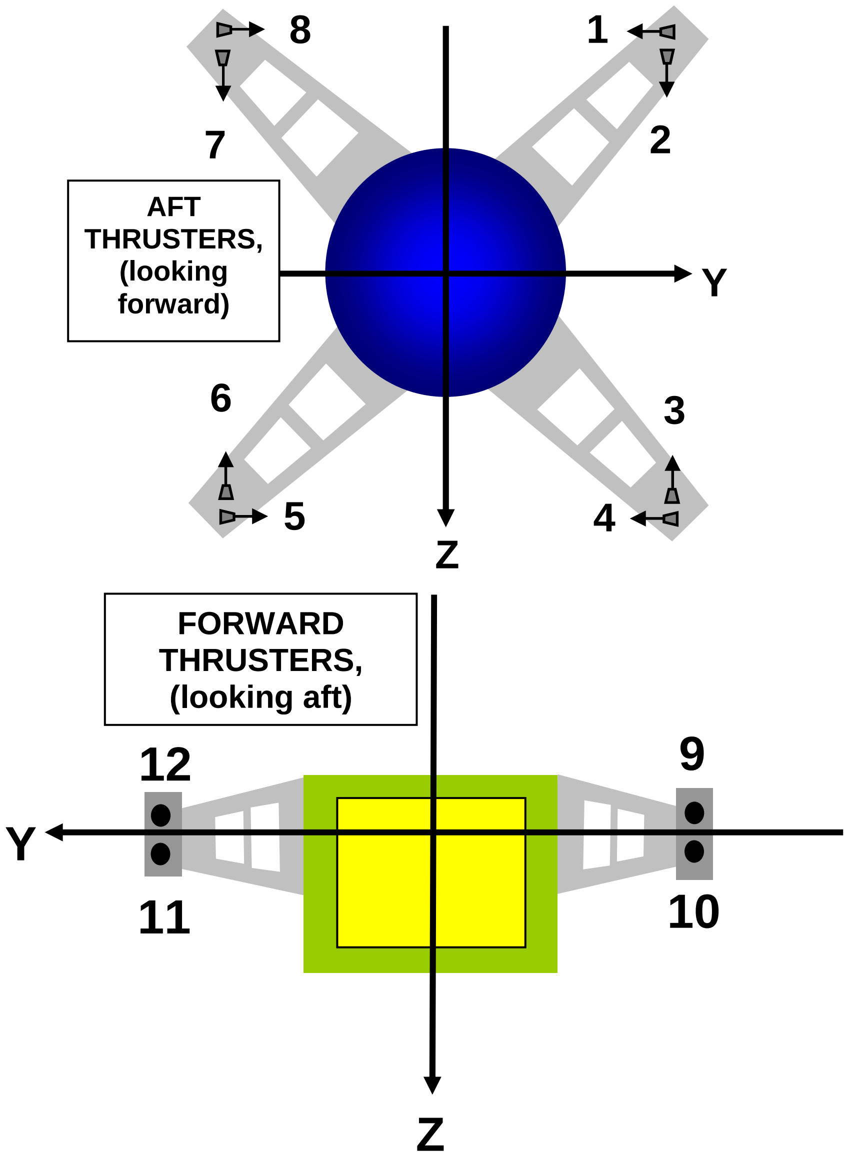

Figure 1a. Thruster Layout, 5 lbf Class, All Canted

Thruster Number	X	Y	Z	RX	RY	RZ
	millimeters			degrees		
1	235	680	-585	0	0	-15
2	235	680	-515	0	-15	0
3	235	680	515	0	15	0
4	235	680	585	0	0	-15
5	235	-680	585	0	0	15
6	235	-680	515	0	15	0
7	235	-680	-515	0	-15	0
8	235	-680	-585	0	0	15
9	4605.72	-632	-60	0	0	0
10	4644.72	-632	60	0	0	0
11	4644.72	632	60	0	0	0
12	4605.72	632	-60	0	0	0

Figure 1b. Thruster Locations and Vectors

1.5.1 SPACECRAFT CENTER OF GRAVITY

Reference center of gravity locations at the beginning of life (BOL) with the nominal propellant load and end of life (EOL) are shown in Figure 2. The sketch includes a representative tank. Detailed mass property data (including S/C configuration, assumptions, and moments of inertia) can be found in the GPM Core Observatory Structural/Mechanical Subsystem Performance Requirement Specification GPM 422-06-01-07-001.

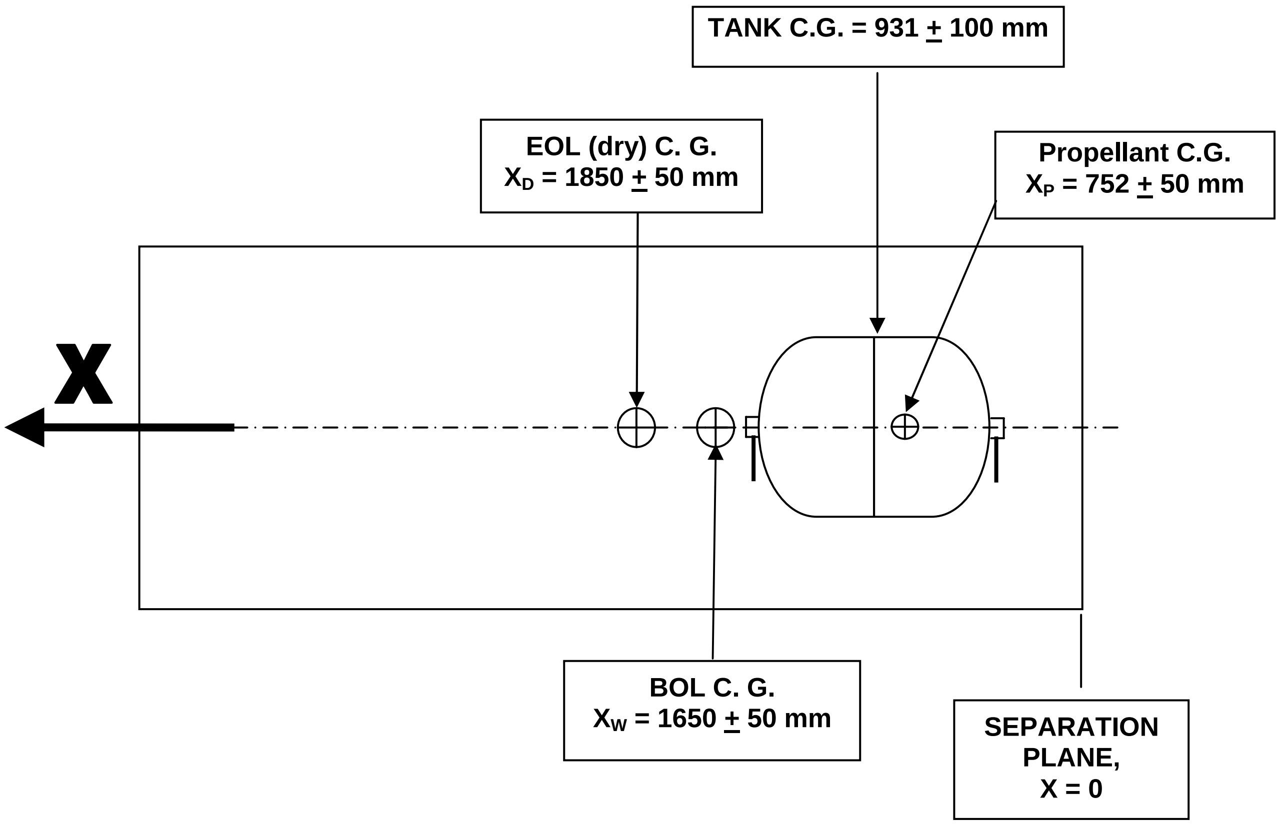

Figure 2. Reference Spacecraft, Tank, and Propellant C.G.

2 GENERAL TANK REQUIREMENTS

For all requirements listed in this document, the term tank shall refer to the definition contained in Section 1 SCOPE unless explicitly stated otherwise. Table 1 is included as a general summary of the more significant requirements contained within this specification. It is included for convenience and for reference. With the exception of the GPM 422-40-01-004 Core Spacecraft Mission Assurance Requirements (MAR), the requirements in the text take precedence over those listed in this table. The Core Spacecraft MAR shall be applicable for all Mission Assurance aspects of the design, construction, and testing of the tank. The cited nominal tank volume in sections that follow is for an unpressurized tank. No corrections are made for tank volume expansion due to pressurization or temperature.

NOTE: Metric pressure units shall be interpreted as absolute pressure unless specifically modified using words such as “gauge” or “differential”

Table 1. Summary of Tank Requirements

Tank Characteristic	Requirement
Safety	ANSI/AIAA S-080-1998, ANSI/AIAA S-081A-2006, AFSPCMAN 91-710, Volume 3, Chapter 12, JERG-0-001, JMR-002A, 45th Space Wing Policy Letter for COPVs, 23 NOV 1993

Table 1. Summary of Tank Requirements (continued)

Design Pressures (Shell Material properties at 50°C)	MDP = 2.758 Mpa gauge (400 psig) ➔ defined at 50°C (122°F) Proof = 3.4475 MPa gauge (500 psig) Burst >5.516MPa gauge (800 psig) (material properties at 50°C / 122°F) Minimum flight pressure (empty tank) = 0.6895 MPa gauge (100 psig) ➔ defined at 15°C (59°F) Minimum Ground Pressure = 0 MPa (0 psia)
Nominal Pressure	Nominal flight pressure ➔ defined at 20°C (68°F) (~339.4 psig)
Temperature	Nominal Temperature = 20°C (68°F), Minimum/Maximum Operating Temperature = 2° - 50°C (35.6°-122°F)
Propellant Compatibility	Hydrazine for 10 years minimum at 20°C, No performance degradation.
Tank Material Elements	COPV , liner = Al 6061, shell = graphite composite, Skirt = graphite composite with metallic inserts
Nominal Fuel Load	545 kg (1201.5 lbm) total, 6.2 kg pressurant, 72% fill fraction (reference)
Maximum Load	@50°C (122°F), 96% of available volume hydrazine (~727 kg) + 2.758 MPa gauge (400 psig) GN_2 pressurant
Minimum Load	50% BOL fill fraction at nominal temperature
Expulsion Efficiency	Minimum ~99%
Minimum Blowdown Pressure	0.6895 Mpa gauge, (100 psig) at 15°C (59°F)
Pressure Cycle Life	10 proof cycles. Ten MDP cycles, Fifty cycles to ½ MDP, Unlimited cycles to 0.3447 MPa gauge, (50 psig). Unlimited vacuum cycles. The sequence of cycles must be specified.

Table 1. Summary of Tank Requirements (continued)

Propellant Flow Rate (steady state – 4 thrusters)	Beginning of life maximum (non-priming) = 0.060 kg/sec (0.133 lbm/sec)
Propellant Flow Rate (w/ACS – 8 thrusters)	Beginning of life maximum (non-priming) = 0.12 kg/sec (0.27 lbm/sec)
Loaded Tank Orientation	Tank is kept within 5 deg of vertical at all times after loading with hydrazine.
Basic Orbit Maneuvers	Separation tip off recovery Drag make up (axial, settling and non-settling) Maneuver ACS and momentum unloading
Basic Orbit Accelerations	Tip off: yaw/pitch 2.0 deg/sec, roll = 0.5 deg/sec Maximum drag: $\pm 7 \times 10^{-7}$ g (maximum drag, minimum mass) Minimum drag: $\pm 5 \times 10^{-9}$ g (minimum drag, maximum mass) Maximum including Solar storm drag: Axial (X axis), $\pm 1 \times 10^{-6}$ g maximum for 7 days 180° Yaw: settling Drag make up maneuver accelerations: 8.7×10^{-3}g settling, 4.5×10^{-3}g non-settling (2850 kg BOL, Maximum pressure)
Drag Makeup Axial Maneuvers	Propellant required (3500 kg BOL) = 2.2 - 1.6 kg /maneuver Burn durations (3500 kg BOL) = 41 sec – 88 sec Minimum time between burns = 3 days
PMD Capacity	1. 5 kg of propellant under the worst case non-settling drag accelerations. 2. 0.5 kg of propellant after exposure to the launch environment 3. Supply up to 5 kg of propellant at the maximum fuel flow rate under the worst case quasi-static thruster induced accelerations.
Slosh Control, Propellant Settling	1. After thruster or wheel maneuver 2. GMI (rotation instrument) forcing

Table 1. Summary of Tank Requirements (continued)

BOL S/C Wet Mass	Minimum = 2850 kg (6401.1 lb), Maximum = 4000 kg (8984 lb) (TBR3)
Tank Packaging Envelope	Nominal/Maximum diameter (inc. support skirt) = 1184 mm (46.61 in) Maximum cylinder diameter (excluding skirt) = 1029 mm (40.51 in) Minimum cylinder diameter (excluding skirt) = 978 mm (38.50 in)

2.1 SAFETY

The tank shall be designed to meet the range safety requirements of the selected Japanese range and U.S. Eastern and Western test ranges. These requirements are specified in JMR-002A Launch Vehicle Payload Safety Standard (JAXA), JERG-0-001, Technical Standard for High-Pressure Gas Equipment for Space Use (JAXA) (April 1, 2004), AFSPCMAN 91-710, Volume 3, Chapter 12, Flight Hardware Pressure Systems and Pressurized Structures, 45th Space Wing Policy Letter for COPVs, 23 NOV 1993 ANSI/AIAA S-080-1998 Space Systems – Metallic Pressure Vessels, Pressurized Structures, and Pressure Components, and ANSI/AIAA S-081A-2006 Space Systems – Composite Overwrapped Pressure Vessels (COPVs).

2.2 MAXIMUM DESIGN PRESSURE (MDP)

The tank shall be capable of operating at its MDP of no less than 2.758 MPa (400 psig) at a temperature of 50 °C (122°F) when empty through fully loaded with propellant and pressurant. Fully loaded includes fills up to 96% of the total tank volume.

2.3 NOMINAL DESIGN PRESSURE (Reference only)

The nominal pressure is defined as the pressure that exists for a tank with 545 kg of propellant which is cooled from 50°C at the MDP to 20°C taking the reduced volume of the hydrazine and the drop in pressure into account. For reference, this results in a nominal pressure at 20°C of approximately 2.340 MPa gauge (339.4 psig).

2.4 PROOF PRESSURE

The tank shall be capable of withstanding a proof pressure of no less than 1.25 x MDP [3.4475 MPa gauge (500 psig)] corrected to 50°C (122°F) material properties and minimum material thicknesses without any permanent physical deformation, yielding or cracking. Note: Stress rupture life issues limit the proof factor to 1.25.

2.5 BURST PRESSURE

The tank shall demonstrate, through a qualification program a burst pressure of no less than 5.516MPa (800 psig) (2.0 x MDP) corrected to 50°C (122°F) material properties and minimum material thicknesses.

2.6 MINIMUM PRESSURE

The minimum internal absolute pressure shall be determined based on a design trade study to be performed by the Contractor. The design goal is for a tank which with an external pressure of 0.1013 MPa (14.7 psia) and an internal pressure of 0.00 MPa (0.00 psia) will not deform, or change such that any tank performance requirements are not met. Further, the goal is to design the tank such that it is capable of unlimited cycles to the minimum pressure. The minimum pressure requirement shall be met using minimum material properties 50°C (122°F) minimum bond line characteristics, worst case voids, and minimum material thicknesses.

2.7 EXPULSION EFFICIENCY

The expulsion efficiency shall be greater than 99% of the unoccupied internal volume (i.e. without PMD) of the tank.

2.8 OPERATING TEMPERATURE

The nominal temperature is 20°C (68°F). The tank shall be capable of operating while containing propellant and pressurant having temperatures ranging from 2°C to 50°C (36° to 122°F). The tank will also be within these temperature limits however the tank temperature may vary from point to point and may not match the average propellant temperature. The tank must be capable of functioning with fluid and tank temperature non-uniformities.

2.9 PROPELLANT FILL FRACTION RANGE

The propellant tank shall be designed to be capable of being loaded to a maximum of 96% of the internal volume at 50°C (122°F). For reference, this corresponds to 727 kg for the baseline 0.7720 m^3 (47111 $in^{3)}$ tank. The minimum BOL fill fraction shall be 50%.

2.10 PROPELLANT COMPATIBILITY

The tank including inlet/outlet tubes shall be compatible with hydrazine (High Purity per MIL-P-26536) for 10 years minimum at 20°C. Compatibility is defined as no performance degradation over the 10 year period including but not limited to expulsion efficiency and pressure holding capability.

2.11 DESIGN LIFE

The tank shall be capable of being used for a minimum of 20 years without requiring repair, maintenance, or retesting. The un-fueled storage temperature shall be between 5° and 45°C (41° and 113°F) with relative humidity between 0% and 100%. The design life is split between dry ground storage and hydrazine loaded as follows:

1. 10 years ground storage.
2. 10 years with hydrazine, 20°C propellant temperature, and pressurized up to MDP (ground and operational).

The tank life requirement for fueled life (ground and space) is 3.5 years for a tank whose fuel temperature is greater than 45°C for 80% of the time it is fueled. The life requirement is between 10 and 3.5 years for propellant temperatures between 20°C and 45°C.

2.12 FLUID COMPATIBILITY

The interior of the tank, including all welds, shall show no degradation due to exposure for a 10 year period at -20° to 60°C (-4° to 140°F), to any of the following gases:

- Nitrogen, MIL-PRF-27401, Grade B Propellant, Pressurizing Agent (see note below)
- Helium per MIL-PRF-27407, Type I, Grade A (see note below)
- Argon per MIL-PRF-27415A (see note below)

NOTE: Hydrocarbon limits for all gases shall be established by the Contractor during the process development effort.

The interior of the tank, including all welds, shall show no degradation after exposure to water at proof pressure and maximum temperature for up to a week. The water shall be reagent water

Type I, Grade A per ASTM D1193-06. Water in contact with the interior of the tank must be free of particulate, hydrocarbon, and live biological agents.

After exposure to the above water, the tank shall be dried by a NASA approved procedure. Drying gases are to be limited to those listed in this section. The temperature of the gases should be limited to 60°C (140°F).

The tank metallic liner shall be constructed of aluminum alloy. All materials used in the construction of the tank assembly and the features they are manufactured into, and end item characteristics (such as perforations, entrapped spaces, crevices, surface roughness, welds, etc) must have proven hydrazine long-term compatibility (minimum 10 year exposure at 20°C (122°F)). Tooling and processes used in the construction of the tank or the treating of its surface shall not introduce incompatible impurities into the tank materials. Surfaces that are treated or processed to enhance wettability or other properties must also be long term compatible with hydrazine while retaining the properties required by the design. The process for treating Al 6061 to enhance wettability detailed in GSFC Al 6061 Wettable Aluminum Treatment Process has been proven to produce highly wettable surfaces that are long term compatible and long term durable with hydrazine.

WARNING: Surfaces that are treated or processed to enhance wettability shall not come into contact with isopropyl alcohol liquid or vapors as such contact has been shown to degrade the wettability aluminum surfaces. This warning applies to all hydrocarbon liquids, vapors, or gasses.

After wrapping, the exterior of the tank, including all welds, shall show no degradation after exposure to any of the following fluids:

- Helium per MIL-PRF-27407, Type I, Grade A

- Nitrogen, MIL-PRF-27401, Grade B Propellant, Pressurizing Agent
- Argon per MIL-PRF-27415A
- Deionized and distilled Water per ASTM D1193-06 Type IV Grade C
- Isopropyl Alcohol per TT-I-735 (Grade A)
- Leak test fluid

After exposure of the tank exterior to any of the liquids above, the tank shall be flushed and dried by vendor prepared and NASA approved procedure.

2.13 HUMIDITY

The unit shall withstand exterior relative humidity up to 100% over a temperature range of 2°C to 29°C (36° to 84° F) without performance degradation. For storage above 29°C, the tank shall withstand a humidity level with the same water content as exists at 29°C and 100% humidity. Internal humidity is controlled by the dry gas used for blanket pressure. All galvanic couples shall be protected per MIL-STD-889.

2.14 STORAGE TEMPERATURE AND PURGE

The tank shall withstand a temperature range of -20° to 60°C (-4° to 140°F) in an empty (no liquid) condition. The pressure inside the tank can range from unpressurized or up to 0.3447 MPa gauge (50 psig) at 20°C (~43 – 57 psig over the temperature range). The tank will contain purge gas except for limited periods of time. The acceptable length of time without purge shall be recommended by the Contractor and approved by GSFC.

2.15 EXTERNAL LEAKAGE

The tank shall demonstrate a total leakage rate of no greater than l x $l0^{-6}$ sccs of GHe with both ports pressurized to the maximum operating pressure of 2.758 MPa

(400 psig). The liner before wrapping shall not leak more than 1 x 10^{-6} sccs when pressurized to the pressure that results in a stress of 0.8 times the tensile strength at the highest stressed location.

2.16 PROPELLANT OFFLAOD

Propellant may be offloaded at the launch site once. Additional offloads will require additional test data to confirm that the performance of the tank will not be compromised by the additional offload cycle. The offload procedure must incorporate tank vendor developed precautions for purge gas, propellant flow rate, tank rinsing/decontamination, drying, and preparations for storage.

2.17 COMPONENT LOADS, VIBRATION, AND CYCLE LIFE

The tank shall adhere to design requirements in this section. In addition, the tank shall have no credible stress-rupture modes based on the stress rupture data and shall have an adequate fatigue life and damage-tolerance life (safe-life) of four times the service life per ANSI/AIAA S-081-A-2006 Section 5.2. The tank liner shall exhibit a leak-before-burst failure mode.

2.17.1 SKIRT TESTING

2.17.1.1 SKIRT STATIC LOAD TEST

To ensure structural integrity prior to installation onto the shell, the skirt shall survive a static load test to 1.5 times the skirt limit level. The skirt limit level shall be derived by applying the component static limit levels in Table 2 to the entire tank system. Each skirt shall be ultrasonically inspected before and after the test. Any change in the c-scan records from before and after this test shall be cause for rejection.

2.17.1.2 SKIRT PROOF TEST

Each skirt and skirt-to-tank joint shall survive a proof test to 1.25 times the skirt limit level by sine burst testing. Signature sweeps (either sine or random vibration) of the tank assembly shall be measured before and after this test. A frequency shift greater than five percent or any evidence of joint failure shall be cause for rejection.

2.17.2 COMPONENT LOADS

All loads presented below are to be reviewed (TBR1) and may change upon completion of coupled loads analysis (CLA). Loads presented are based on a less precise base drive analysis. The tank shall have positive margins of safety due to load requirements in this section.

The tanks shall withstand the acceleration loads described in Table 2 while loaded to a 96% fill fraction at 50°C and pressurized to MDP. Loads for each load case are considered to act simultaneously. All load combinations must be considered. Test levels should be developed such that peak stress levels, from defined load cases for fully loaded tank (pressurized to MDP), are obtained during the test. Unless the tank design, including PMD, can be shown to have been qualified to equivalent levels, verification of this requirement shall be by test performed in accordance to GPM 422-06-01-002 "GPM Core Spacecraft Mechanical Environmental Loads and Test Requirements Document" TBD5 Refer to 7 for test factors and test durations.

Table 2. Load Requirement (Limit Levels)

Axis	Limit Level (g)
Axial	±6.5
Lateral	±3.0

2.17.3 SINE VIBRATION

The tank shall be capable of surviving the sinusoidal limit loads given below in Table 3 while loaded to a 96% fill fraction and pressurized to MDP. Sine loads are to be applied in each axis individually. All swept sine vibration testing shall be notched such that design limit loads are not exceeded.

Table 3. Propellant Tank Sine Specifications

Axial Direction

Frequency (Hz)	Acceptance Limit Level (g)	Qualification Limit Level (g)
5-50	2.0	2.5

Lateral Direction

Frequency (Hz)	Acceptance Limit Level (g)	Qualification Limit Level (g)
5-50	2.0	2.5

2.17.4 SHOCK

The tanks shall be capable of withstanding the predicted shock levels given below in Table 4. Unless a specific component is susceptible to the shock environment, all shock testing will be deferred until the spacecraft level of assembly.

Table 4. Propellant Tank Shock Specification (at skirt)

Frequency (Hz)	Acceptance Limit Level (g)
100	24.4
1430	2300
20000	2300

2.17.5 MINIMUM NATURAL FREQUENCY

The minimum structural resonant frequency (fixed base) of the propellant tank shall be above 50 Hz in the launch direction (spacecraft X direction) and above 30Hz laterally (spacecraft Y-Z directions) when fully loaded with propellant (50 – 96% fill fraction) and pressurized between 2.068 and 2.758 MPa gauge (300 and 400 psig).

2.17.6 RANDOM VIBRATION ENVIRONMENTS

The tank shall be capable of withstanding the random vibration limit levels of Table 5 while empty and at 75 psig pad pressure. Levels are to be applied in each component axis separately. The tank shall be designed to withstand the vibration spectrum without any damage or degradation in performance.

Table 5. Propellant Tank Random Vibration Specification - Dry

Frequency (Hz)	Acceptance Limit Level (g^2/Hz)	Qualification Limit Level (g^2/Hz)
20	0.013	0.026
50	0.04	0.08
800	0.04	0.08

Table 5. Propellant Tank Random Vibration Specification – Dry (continued)

2000	0.013	0.026
G_{RMS}	7.36 g_{rms}	10.0 g_{rms}

The tanks shall withstand the random vibration levels of Table 6 while loaded to any fill fraction between 50 – 96% and pressurized to MDP. Levels are considered to act in each component axis separately.

Note: The acceptance level is the same as the qualification level in frequency ranges where flight predicts fall 3dB or more below GSFC workmanship standards.

Table 6. Propellant tank Random Vibration Specification - Full

Frequency (Hz)	Acceptance Limit Level (g^2/Hz)	Qualification Level (g^2/Hz)
20	0.010	0.010
2000	0.010	0.010
Overall	4.45 g_{rms}	4.45 g_{rms}

2.17.7 TEST FACTORS

The factors shown in Table 7 shall be used in the testing of the tank.

Table 7. Test Factors and Durations

Test	Prototype Hardware	Protoflight Hardware	Flight Hardware
Structural Loads Level Duration Centrifuge/ Static Load Sine Burst [1]	1.25 X Limit Load 1 Minute 5 Cycles Full Level/Axis	1.25 X Limit Load 30 Seconds 5 Cycles Full Level/Axis	Limit Load 30 Seconds 5 Cycles Full Level/Axis
Acoustic Level Duration [3]	N/A	N/A	N/A
Random Vibration Level Duration	Limit Level +3dB 2 Minutes/Axis	Limit Level +3dB 1 Minute/Axis	Limit Level 1 Minute/Axis
Sine Vibration Level Sweep Rate [2]	1.25 X Limit Level 2 Octaves/Minute/ Axis	1.25 X Limit Level 4 Octaves/Minute/ Axis	Limit Level 4 Octaves/Minute/ Axis
Shock Actual Device Simulated [3]	N/A	N/A	N/A

(1) Sine burst testing must be done at a frequency sufficiently below primary resonance as to ensure rigid body motion.

(2) Unless otherwise specified, these sine sweep rates apply.

(3) Acoustic and shock testing will not be performed on the tank separate from the spacecraft

2.17.8 CYCLE LIFE

The tank shall operate after a minimum number of pressure cycles detailed in Table 8 applied in any order. As implied in Table 8, the tank shall operate after unlimited internal minimum pressure cycles. Environmental loads (ground handling, transportation, acceptance testing, and launch) shall be included in the cycle life design and analysis. Actual planned sequence of cycles must be specified. ANSI/AIAA S-081A requires that pressure cycle test and safe-life test repeat the sequence four times.

Table 8. Pressure Cycle Life

NAME	NUMBER	PRESSURE RANGE, METRIC (ENGLISH)
Proof Pressure*	10	0** MPa - 3.447 MPa - 0 MPa (0 psia - 500 psig - 0 psia)
MDP	10	0 MPa - 2.758 MPa - 0 Mpa (0 psia - 400 psig - 0 psia)
TEST	50	0 MPa - 1.379 MPa - 0 Mpa (0 psia - 200 psig - 0 psia)
BLANKET	UNLIMITED	0 MPa - 0.3447 MPa - 0 Mpa (0 psia - 50 psig - 0 psia)

*A pressure cycle will be counted as a proof pressure cycle if it is > 405 psig

** 0 Mpa/0 psia used to signify minimum internal pressure

3. PROPELLANT MANAGEMENT DEVICE (PMD) PERFORMANCE REQUIREMENTS

3.1 SCOPE

This section covers the detailed requirements that shall be used for designing the PMD. It covers the requirements derived from ground and flight environments and the material selection, processing and handling requirements.

3.2 PMD PERFORMANCE REQUIREMENTS

3.2.1 PMD GENERAL OPERATING REQUIREMENTS

All PMDs procured under this section for use in tanks described in this development specification shall meet the following general requirements.

3.2.1.1 PMD MATERIAL

The PMD shall be constructed of aluminum alloy per AMS-QQ-A-250/11. The use of Al 6061 is preferred due to its proven long term compatibility with hydrazine and its proven ability to be consistently processed such that a durable high wettability (contact angle less than 5 degrees) surface is produced. All materials used in the construction of the PMD assembly must have proven hydrazine long term compatibility. Tooling and processes used in the construction of the PMD shall not introduce incompatible impurities into the PMD material. PMD surfaces that must wet shall be processed using the Wettable Aluminum 6061 Treatment Process or similar process that is well characterized. The GSFC process has been shown to reliably produce hydrazine/Al6061contact angles less than 5 degrees. Al 6061 treated with the GSFC process has also been shown to retain contact angle performance after 10 years of simulated aging in 20°C hydrazine. The aluminum treatment process chosen by the Contractor shall reliably produce surfaces with hydrazine contact angles which meet or exceed design criteria for contact angle specified by the Contractor for their design. The Contractor selected aluminum treatment process shall retain the contact angle performance required by the Contractor’s design after exposure to 20°C hydrazine for 10 years. The PMD surfaces that must wet shall be maintained such that the contact angle performance required by the Contractor’s design is preserved prior to launch site propellant loading.

3.2.1.2 GAS FREE PROPELLANT DELIVERY

The PMD tank shall provide a continuous gas-free flow of liquid at the tank outlet between the maximum and minimum flow rates over the entire mission. The instantaneous peak transient flows caused by a manifold priming or surge event shall not cause structural damage to the PMD.

3.2.1.3 PROPELLANT TANK FILL FRACTIONS

The propellant tank fill fraction is defined as the ratio of liquid volume at 20°C (68°F) to total usable tank volume. Although the tank will be design to be structurally capable of containing up to 96% fill at 50°C (122°F), the PMD will be designed around the nominal propellant load of 545 kg (1201.5 lbm). No PMD design features will be employed which preclude successful PMD operation for BOL fill fractions as low as 50% at 20°C.

3.2.1.4 MASS FOR WORST CASE ACCELERATIONS AND RATES (TBR3)

The PMD performance requirements shall be met over body linear and angular accelerations and rates specified in this document. Beginning of life wet mass can range from a minimum = 2850 kg (6401.1 lb) to a maximum = 4000 kg (8984 lb). Worst case conditions are to be calculated based on a mass within this range.

3.2.1.5 PRESSURE DROP

The pressure drop, from the tank to the outlet tube, shall be less than 0.006895 MPa, (1 psid) at the maximum (non-priming) flow rate = 0.12 kg/sec (0.27 lbm/sec).

3.2.1.6 TANK INTERNAL MATERIAL COMPATIBILITY WITH PMD

No materials used in processing or manufacture of the tank interior shall cause performance degradation of the PMD elements upon assembly of the tank interior. The mechanisms for such degradation might include but are not limited to contact contamination, outgassing and redeposition, and leaching and redeposition.

3.2.2 GROUND OPERATIONS

The ground operations include propellant tank loading/offloading, pressurization/depressurization, transport from the loading facility, and integration of the S/C to the launch vehicle.

3.2.2.1 LOADING, PRESSURIZATION

The propellant tanks shall always be loaded and pressurized (pre-launch) in a vertically upright position (liquid port down) with the spacecraft X-axis vertical. Safe loading flow rates for water or hydrazine are specified in the Tank Operational Constraints Document. Safe pressurization rates are specified in the Tank Operational Constraints Document.

3.2.2.2 OFFLOADING, DEPRESSURIZATION

The propellant tanks shall always be offloaded and depressurized (pre-launch) in a vertically upright position (liquid port down) with the spacecraft X-axis vertical. Safe offloading flow rates for water or hydrazine are specified in the Tank Operational Constraints Document. Safe depressurization rates are specified in the Tank Operational Constraints Document.

3.2.2.3 TRANSPORT AND S/C INTEGRATION WITH LAUNCH VEHICLE

The spacecraft including the loaded and pressurized propulsion subsystem will be transported from the preparation facilities to the launch pad in a vertical orientation. The spacecraft will be lifted to the top of the launch vehicle while remaining in a vertical orientation. For the purposes of this section, vertical is defined as maintaining the axis of the tank within a 5° half angle cone. The PMD is designed to function properly after tilting within a 5° half angle cone from vertical during ground handling. The PMD is designed to function properly while loaded after being exposed to transportation during ground handling. All loads and environments for the operations listed in this section are detailed in *TBD3 (transportation document or a launch site specification)*.

3.2.3 FLIGHT OPERATIONS

The PMD shall provide gas-free propellant flow on demand during all phases of flight under all orbit initiation and on-station operating conditions. The basic thruster operations are for booster separation tip off recovery, drag makeup DV, and drag make up maneuver attitude control.

3.2.3.1 OPERATIONAL FLOW RATES

The PMD flow rate requirements shall be met under worst case minimum and maximum steady state flow rates and thruster firing durations. The specified flow rates are based on density of 1.0083 g/cc for hydrazine at 20°C (68°F). Beginning of life maximum (non-priming) flow rate = 0.12 kg/sec (0.27 lbm/sec) is based on 4 – 5 lbf class thrusters firing steady state plus 4 – 5 lbf class thrusters firing for ACS control at 2.76MPa (400 psi). Table 9 below can be used for typical performance of a single thruster.

3.2.3.2 DURATIONS AND THRUSTER USE

The PMD performance requirements shall be met over the durations and thruster usage specified in this document. The PMD shall be capable of performing with any combination of thrusters firing and for any pulse widths greater than 40 msec. Thruster locations are shown in Figure 1b. All thrusters are 5 lbf (22 N) class. Table 9 below can be used for typical performance of a single thruster.

Table 9. Typical Thruster Performance

Inlet Pressure (psi)	Inlet Pressure (Mpa)	Isp (sec)	Thrust (lbf)	Thrust (N)	Mass Flow (lbm/sec)	Mass Flow (kg/sec)
400	2.758	235.73	7.829	34.82	0.03321	0.01506
350	2.413	235.44	7.047	31.34	0.02993	0.01358
339.4*	2.340	235.36	6.878	30.59	0.02922	0.01326
300	2.069	235.04	6.240	27.76	0.02655	0.01204
250	1.724	234.48	5.405	24.04	0.02305	0.01045
200	1.379	233.65	4.533	20.16	0.01940	0.00880
150	1.034	232.26	3.613	16.07	0.01555	0.00706
100	0.690	229.47	2.624	11.67	0.01144	0.00519

***Nominal Tank Pressure@20C**

3.2.3.3 BOOSTER SEPARATION TIP OFF

The PMD must supply propellant to be used to null 2.0 deg/sec pitch or yaw rates and 0.5 deg/sec roll rates assuming worst case BOL mass and CG. 0.5 kg (1.1lbm) of propellant shall be available after exposure to the launch environment and 2 hours of maximum tip-off rate environment. 0.5 kg is required to be available within 5 minutes of separation from the launch vehicle under the worst case tip off rates. The launch vehicle events are detailed in the GPM Core Observatory to H-IIA Interface Requirements Document (422-40-03-100).

3.2.3.4 SPACECRAFT DRAG

The spacecraft design drag acceleration (maximum) in the X axis is $\pm 7 \times 10^{-7}$ g. The spacecraft performs periodic 180 degree yaw maneuver thus drag accelerations may be in the settling or non-settling direction. The minimum drag induced acceleration is $\pm 5 \times 10^{-9}$ g. The PMD shall be designed such that 5.0 kg (11 lb) of propellant is available under the worst case atmospheric drag induced accelerations.

3.2.3.5 SOLAR STORM DRAG

Solar storms can increase the drag accelerations on the spacecraft. The worst case solar storm is assumed to increase drag to ±1 x10-6 g maximum for 7 days. The PMD shall provide 2.5 kg (5.5 lb) of propellant at the conclusion of 7 days of the worst case solar storm induced accelerations.

3.2.3.6 DRAG MAKEUP MANEUVER THRUST

The primary mode of operation for the thrusters is performing drag make up maneuvers. These maneuvers may be performed in either the settling or non-settling direction. The direction is swapped every 60 days (maximum). Maneuvers with thrust accelerations in the settling direction will use 4 to 8 thrusters continuously throughout the maneuver. Up to two non-settling thrusters at a time may be short pulsed for attitude control during a settling direction burn. Maneuvers with thrust accelerations in the non-settling direction will use 2 to 4 thrusters continuously throughout the maneuver. Up to two settling thrusters at a time may be short pulsed for attitude control during a non-settling direction burn. The propellant required for a drag makeup maneuver is 2.2 kg (BOL) - 1.6 kg (EOL) (4.2 - 3.1 lbm)/maneuver. Based on a BOL mass of 3500 kg, burn durations are 41 sec at BOL and 88 sec at EOL. The minimum time between burns is 3 days. The PMD shall supply 5 kg of propellant after a maximum of 3 days following a tip off maneuver or an axial maneuver. The maximum number of drag makeup maneuvers is 300 and is divided roughly evenly between the forward and backward flight directions.

3.2.3.7 YAW MANEUVER

Yaw maneuvers are performed by momentum wheels. The maneuvers will occur periodically due to thermal affects and on occasion for calibration purposes. The baseline 180 degree yaw maneuver requires 10 minutes. It is modeled as accelerate for 45 deg over 200 seconds, coast for 90 deg over 200 seconds, decelerate for 45 deg over 200 seconds. The acceleration profile is noted below.

Accelerate/decelerate: tangential acceleration = 4.00 x10^{-6} g,

centripetal acceleration = 0g to 6.29 x10^{-6} g

Coast phase: 0.007854 rad/sec = 0.450 deg/sec,

tangential acceleration = 0 g,

centripetal acceleration = 6.29 x10^{-6} g

Note that the baseline 180 degree yaw maneuver is a simplification of the actual maneuver to be used for ROM maneuver effects.

3.2.3.8 CENTER OF MASS AND SLOSH CONTROL

The PMD is not required to provide center of mass control of the propellant. The spacecraft will nominally be rotated to the correct attitude for science operations or engineering operations (such as firing thrusters) using reaction wheels, not thrusters. Thrusters may be needed for this function in a backup mode. The PMD shall be designed such that the forces due to propellant movement associated with any disturbance (thruster or momentum wheel maneuver, GMI disturbance) should settle to less than 0.005 Nm on the S/C in each axis within 5 minutes of the end of a maneuver

The reference GMI disturbance is characterized by the following: (32 RPM, [2.95, 2.95, 5.47] Nm oscillating torque). The PMD will be designed such that coupling between the GMI disturbance and the propellant does not occur for fill fractions between 96% and 1%. This requirement is waived if the disturbance due to coupling is less than 0.005 Nm on the S/C in each axis.

3.2.4 IN-FLIGHT PROPELLANT FEED SYSTEM PRIMING

The initial subsystem instantaneous surge flow rate transient capability of PMD shall be calculated by the PMD designer. The transient condition is caused by potential pressure differential across the latch valves between the tank outlet and the thrusters. The maximum volume down stream to be filled during priming is TBD4 cc at 0.0 MPa (0.0 psia). Although a flow limiting device shall be designed by GSFC and installed in the propulsion manifold, the PMD flow rate during priming shall be calculated without corrections to account for the flow limiter. The maximum rotation environment during the priming event shall be: pitch/yaw = 2.0 deg/sec, roll = 0.5 deg/sec. The PMD shall be designed such that the priming event causes no degradation to the PMD performance.

3.2.5 PMD PERFORMANCE MARGIN

The PMD performance margin is defined as the ratio of bubble point to the sum of all hydrostatic, and hydrodynamic (friction) loadings on the PMD. The PMD performance margin shall be a minimum of two and preferably higher at all times for nominal mission and the contingency tip-off maneuver.

4 DESIGN AND CONSTRUCTION

4.1 VOLUMETRIC CAPACITY

The tank nominal capacity is 545 kg of hydrazine at 20°C and is designed for blowdown mode. Blowdown will be from 2.758 MPa, (400 psia) at 50°C (122°F) to 0.6895 MPa, (100 psia) at 15°C (59°F). For reference, this should result in a tank with an internal volume of approximately 0.7720 m^3 or 47111 in^3. This assumes that the PMD and other internal feature volumes plus residual propellant volume equals approximately 1% or less of the initial hot (50°C) propellant volume. The minimum loading of the tank is 50% of the tank volume at 20°C.

4.2 MECHANICAL CAPACITY

The nominal mode for the tank is blowdown. For the 545 kg (1202 lbm) load of hydrazine and the baseline .772 m^3 (47111 in^3) tank this corresponds to 6.2 kg of pressurant. The tank shall be capable of supporting a maximum propellant load of a 96% full tank at 50°C (122°F). This corresponds to 727 kg load for the baseline tank volume. The GPM structure will not be designed to support a 727 kg load however the tank will be capable of loadings higher than 545 kg for future missions.

4.3 WEIGHT

The tank weight including the PMD shall not exceed 45 kg (99 lbs).

4.4 SHAPE AND SIZE

Envelope dimensions presented in this specification are for reference only. The mechanical interface control drawing (MICD) GD 2085095 (see Applicable Documents) shall take precedence over this specification.

4.4.1 TANK BODY AND ASSEMBLY ENVELOPE

The tank shall be cylindrical in shape with end domes shaped to minimize mass per tank volume by using the inherent excess composite mass in the dome end to structural advantage (isotensoid shape). The tank cylinder shall fit into a cylindrical envelope 1021.6 mm (40.22 in.) in diameter, maximum, excluding the support skirt. The minimum cylinder diameter shall be 978 mm (38.5 in). The envelope includes the dynamic envelope. The dynamic envelope includes allowance for all displacements and deflection associated with the limit loads. The maximum length including outlet bosses shall be governed by the MICD. The relative location of the skirt on the tank is also governed by the MICD.

4.4.2 SKIRT CONFIGURATION

The skirt shall interface to the inside diameter of a cylinder approximately 1182 mm (46.54 in) in diameter. The design of the skirt shall allow space for a shim between the tank and the spacecraft. The exact details of the interface between the tank and the spacecraft will be governed by the MICD.

4.5 LINER THICKNESS

The baseline thickness of the thinnest membrane of the liner shall range from 0.762 to .889 mm (0.030 - .035 inch). Changes to the baseline minimum thickness can affect the tank's ability to demise are to be subjected to demise analyses prior to approval. The liner shall be designed such that greater than 40% of the liner by surface area has a wall thickness < 1.27 mm (.050 inch). This will ensure the demisability of the tank.

4.6 COMPOSITE OVERWRAP AND SKIRT MATERIAL

The composite overwrap material shall be carbon fiber in an epoxy resin matrix. This composite material shall not outgas more than 1.0 percent by weight nor contain collected volatile condensable materials (VCM) in excess of 0.1 percent by total weight when tested per ASTM E595. The skirt shall be installed onto the tank in a separately cured operation from the curing of the wrap. The overwrap shall be designed such that greater than 40% of the liner by surface area has a wall thickness < 2.8 mm (0.11 inch). This will ensure the demisability of the tank.

4.7 FLUID INTERFACES

4.7.1 INLET BOSSES

If the propellant and pressurant inlet bosses are not integral to the liner, the requirements in this subsection shall apply. The primary interface between the boss and the liner shall be a welded joint. The design of the internal surfaces of the boss and tank features within the boss shall not trap liquids or liquid born debris such that rinsing, cleaning, or drying operations are hampered.

4.7.2 PRESSURANT INLET

The pressurant inlet tube shall be 0.25 inch OD with a 0.028 inch wall thickness, and the material shall be 304L CRES (stainless steel) for at least the last 50 mm (~2”) of its length. The axis of the last 50 mm (~2 in) of the inlet tube shall be perpendicular to the long axis of the tank to within 0.5°.

4.7.3 PROPELLANT OUTLET

The outlet tube shall be 0.375 inch OD with a 0.028 inch wall thickness, and the material shall be 304L CRES for at least the last 50 mm (~2 in) inches of its length. The axis of the last 50 mm (~2 in) of the outlet tube shall be perpendicular to the long axis of the tank to within 0.5°.

4.7.4 INLET AND OUTLET TUBE LOCATIONS

The inlet and outlet tubes shall be approximately as indicated in Figure 3. Figure 3 is to be used only as a guideline for the vendor. Design criteria or Inspection requirements may dictate a configuration which differs from the illustration. The tube shall be long enough to give a clearance between the tube center line and the surface of the tank of approximately 76 mm (~3”). Actual tube length shall be determined by the vendor and the customer such that the customer’s weld equipment has adequate clearance with the tank wall. Relative clocking of the inlet/outlet tubes and tube length will be per vender produced and GSFC approved ICD.

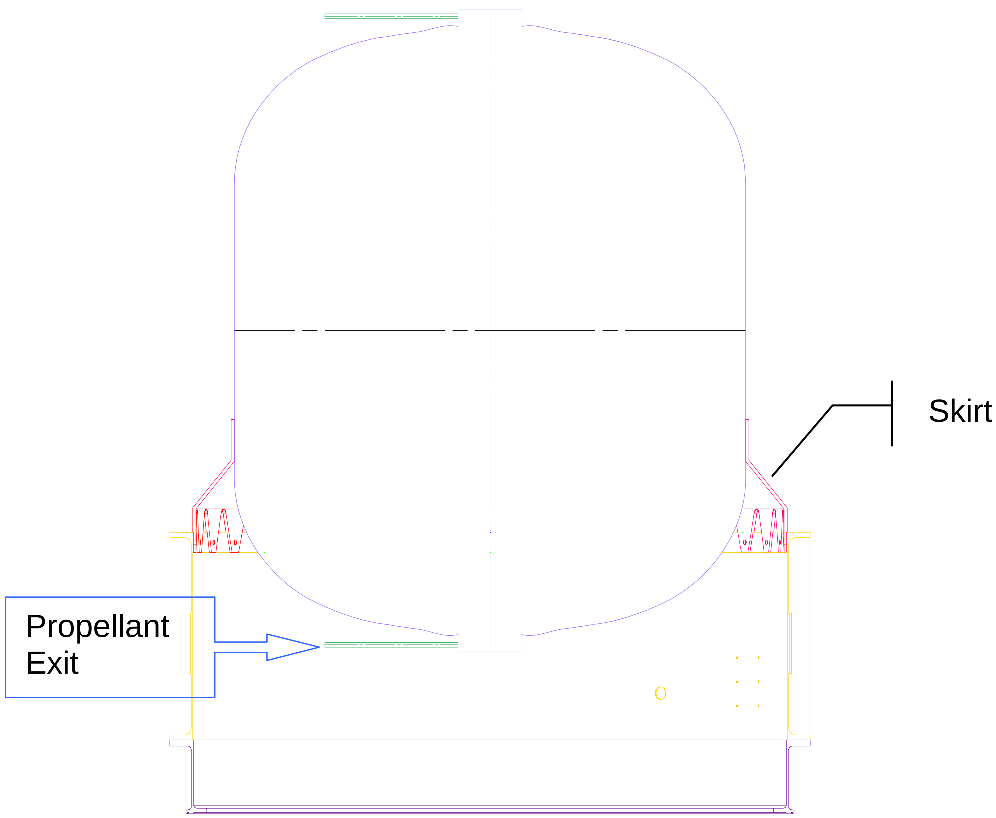

Figure 3. Basic Tank Configuration

4.8 INLET AND OUTLET TUBE DESIGN PRESSURES

4.8.1 INLET AND OUTLET TUBE CYCLING, PROOF PRESSURE

The inlet and outlet tubes and fittings shall be capable of withstanding the pressure cycle environment without any permanent physical deformation, yielding or cracking. The analytic proof pressure capability shall meet the requirements of the applicable documents for tubes.

4.8.2 INLET AND OUTLET TUBE BURST PRESSURE

The vendor shall demonstrate, through a qualification program or by similarity, that the inlet and outlet tubes and fittings have a burst pressure of no less than 11.03 MPa gauge (1600 psig).

4.9 MOUNTING

The mounting of the tank shall be accomplished with a skirt type mount using 24 or 36 tabs. The skirt attachment points shall be designed to provide thrust load paths and to minimize [< 444.8 N (< 100 lbs)] the radial reactions at the side attachment points for the tank in the loaded and pressurized (MDP) state. The skirt shall allow for four equally spaced 38.1 mm diameter (1.5 inch) plan view penetrations for routing of the pressurant line and harnessing. The clocking of the skirt mounting tabs with respect to the pressurant outlet tube shall be included in the vendor produced ICD and is subject to GSFC approval. The skirt shall interface to the inside diameter of a cylinder approximately 1182 mm (46.54 in) in diameter. The skirt geometry shall be such that a gap of 25.4 mm (1 in.) minimum exists between the inside of the skirt at the fastener hole center line and the tank outer surface for tool and fastener clearance. See Figure for definition of the skirt to tank gap. The tank shall be mounted with the propellant exit down as shown in Figure 4.

The skirt shall be mounted to the tank cylinder as far aft as possible based on robust design practices.

The skirt attachment points shall be designed to provide thrust load paths and to minimize the radial reactions at the side attachment points. The interface surfaces of the skirt shall provide a close-tolerance bearing surface. The bearing loads applied to this surface shall be transferred through a bonded joint to the adjacent composite material. A shim shall be used at each mounting location during installation between the tank skirt and the spacecraft primary structure. The mounts shall be deflected during tank installation such that a nominally zero stress state exists in the critical sections of the mounts when the tank is pressurized to the nominal launch pressure at 20°C.

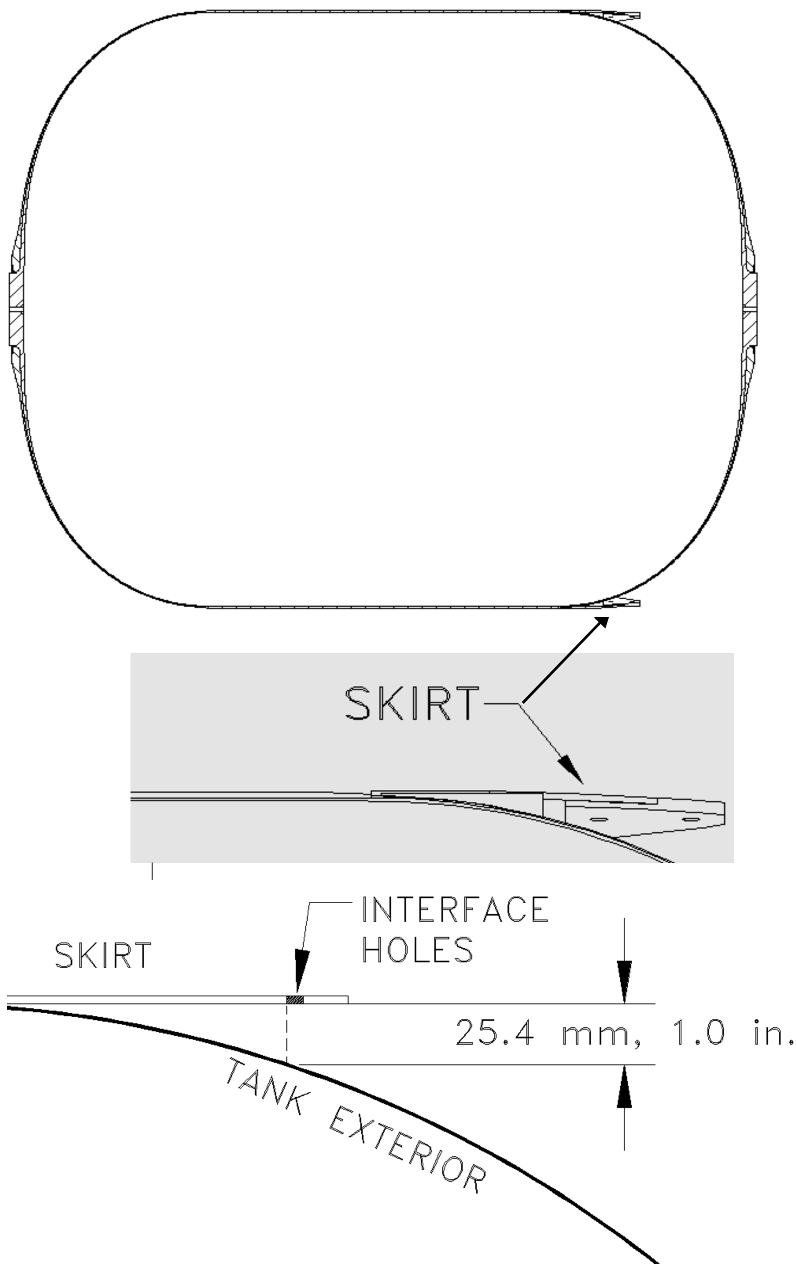

Figure 4. Skirt details (straight skirt shown)

4.10 WELDING

Welding shall be performed and inspected per a vendor developed and NASA approved procedure. Control of weld filler material shall also be per vendor and NASA approval. The welding process shall be qualified on a representative full-size ring. The weld shall be left in the "as-welded" condition.

4.11 METALLIC and COMPOSITE MATERIAL SELECTION

Metallic and composite materials shall be selected based on requirements in ANSI/AIAA S-080-1998 and ANSI/AIAA S-081A-2006. Metallic materials should have A-basis allowables determined based on tests data or from DOT/FAA/Ar-MMPDS-02. A-basis allowables for composite materials should be found using the procedure stated in ANSI/AIAA S-081A-2006 Section 5.3.

4.12 CONTACT ANGLE CRITICAL SURFACES

All internal parts or surfaces which are contact angle critical shall be handled and stored in such a way that the contact angle performance is not degraded. The vendor shall verify contact angle performance prior to close-out of the tank.

4.13 FUNGUS INERT MATERIAL

All materials used in the tank shall be fungus inert in accordance with MIL-STD-810F. All test liquids shall also be fungus inert.

4.14 CORROSIVE METALS

All materials used in the tank shall be corrosion resistant.

4.15 DISSIMILAR METALS

The compatibility of two materials in intimate contact shall be established from Table I of MIL-STD-889B. The interaction of dissimilar metals shall not cause changes to the tank's compatibility with hydrazine.

4.16 LUBRICANTS

No lubricants shall be used in the build and test of the tank.

4.17 INTERCHANGEABILITY

Each tank assembly shall be directly interchangeable physically and functionally with other items of the same part number.

4.18 IDENTIFICATION AND MARKING

The tank shall be marked in accordance with MIL-STD-130L, and shall include but not be limited to the following:

1) Vendor Part Number
2) Vendor Name
3) Vendor Serial Number
4) Contract Number

5) Unit Name

6) Weight

4.19 SHIPPING AND PACKAGING REQUIREMENTS

Unless otherwise specified in the contract or purchase order, units procured to this specification shall be packaged, packed, and marked for shipment as specified herein.

4.19.1 WRAPPING

Mounting surfaces and ports shall be protected with pads that shall not cause tank deterioration. Each tank port shall be protected from contamination entering the tank. Each tank shall be wrapped in a clean nylon non-static bag retained in place by pressure-sensitive tape applied only to the bag surface itself. A second sealed plastic bag shall be placed over the inner bag. A legible tank identification card shall be taped to the outer surface of the inner bag so that the card is readable without opening the outer bag.

4.19.2 SHIPPING CONTAINER

Each unit shall be placed in a separate container that conforms to a design developed by the vendor and approved by NASA GSFC. The container shall be pre-lined at top, bottom, and sides with foam cushioning material. After the unit is placed in the container, additional cushioning material shall be used to fill all voids and prevent movement of the tank during handling and shipping. The shipping container shall provide protection for each tank during shipment and handling and shall meet the minimum packaging requirements of the common carrier (if so shipped) for safe transportation to the point of delivery. The shipping container shall be marked stating that the contents are high value space flight hardware and with identification stating the weight and contents.

4.19.3 PROTECTIVE COVERS

During assembly and integration, when processing does not prohibit, all areas of the tank that are exposed to impact shall be covered with covers sufficient to prevent impact damage from credible threats. When processing requires the cover to be removed while an impact threat still exists, a certified witness shall observe the tanks to record any impacts. Protective covers shall comply with AIAA S-081A-2006.

4.20 STORAGE

Each tank shall be stored in a container that will protect the tank from impact damage. The unit will be capable of being stored without intervention for 5 years and with a single intervention for 10 years. Initial blanket pressure shall be 0.3447MPa (50 psig) of dry GN2, argon, or xenon. A method of monitoring internal pressure will remain attached to the gas port of the tank during storage. Design features shall be incorporated such that storage pressure is maintained above 0.03347MPa gauge (5 psig) over the 5 years of storage. Mechanical means for supporting the pressure gage and eliminating loading of the outlet shall be employed. Storage after tank acceptance testing including shipping and after propulsion subsystem testing shall be considered storage conditions and shall require blanket pressure.

4.21 DOCUMENTATION

Except as otherwise negotiated with the NASA customer, all required reliability and test documentation such as test reports, certifications, shipping invoices, etc., shall be packed in the tank container. All qualification and acceptance test data and analysis shall be documented per AFSPCMAN 91-710v3, JMR-002A, and JERG-0-001. Documentation shall be maintained throughout the life of the pressure vessel.

5 QUALITY ASSURANCE PROVISIONS

5.1 TEST RESPONSIBILITY

The contractor is responsible for all verification activities unless otherwise noted in the SOW or contract. The contractor may choose to use an outside testing facility subject to the approval of GSFC. GSFC reserves the right to witness all verification testing.

5.2 TEST TOLERANCES

The test condition tolerances shall meet all requirements set forth in SMC-TR-04-17. Additionally, the following tolerances shall apply.

- Fluid Pressure: ±0.006895 MPa, (±1 psi), except PMD bubble point testing. Bubble point test pressure tolerance is per vendor procedure.

5.3 TEST MEASUREMENTS

All test measurement devices and instrumentation shall be in compliance with MIL-STD-45662A.

5.4 NON-DESTRUCTIVE EXAMINATION

The term dome as used in this section is meant to include the rounded end of a tank plus any short cylindrical section that is part of it. If the tank is made of two domes plus a separate cylindrical section (not preferred) then the cylindrical section is to be inspected in the same manner as the domes. Before welding the tank domes together, all surfaces, including the inside and outside surfaces of each dome, shall be dye penetrant inspected in accordance with GSFC-S-313-009, "Fluorescent Penetrant Test Method Requirements and Guidelines" or equivalent NASA approved vendor procedure. The inspection must also take place prior to the application of any special cleaning or treatment process to the dome. The inspection shall be Special level in accordance with section 3.2b of GSFC-S-313-009 or equivalent vendor procedure. Note that inspectors performing Special level inspections shall have a Special level certification. The Special level certification is assigned to individuals who have demonstrated the ability to reliably detect flaws smaller than Standard level sizes. All surfaces of the tank domes shall be etched per customer approved vendor procedure before being penetrant inspected. All detected cracks, flaws, inclusions and other indications shall be reported to GSFC for disposition.

Particular care must be taken with the liner such that no contamination from the liner may contaminate the aluminum PMD. The wettability of the PMD is highly sensitive to contamination especially from hydrocarbons. After all processing steps for the tank liner are completed (including penetrant inspection and pre-overwrap preparations) the inner and outer surfaces must be cleaned such that all hydrocarbons and other volatile substances are removed and verified to levels to be determined by Contractor study using procedures subject to GSFC approval. The vendor shall apply any special contact angle enhancing processes only after GSFC has approved the penetrant inspection results. The shells must then be stored in a dry hydrocarbon free environment of nitrogen or under water. The grades of nitrogen and water are per the specifications of Section 0. The storage containers must not degrade the purity levels of the gas or water.

After welding the sections of the metal membrane together, the weld area shall be radiographic and penetrant inspected (outside only). The number of inspections to be conducted shall be agreed upon by the government technical officer and the appropriate vendor representative. Both inspections shall be performed to Special level. The inspector performing the Special level radiographic inspection shall have a Special level certification. The radiographic inspection shall be performed in accordance with MIL-STD-453C, "Inspection, Radiographic" or equivalent procedure. All detected cracks, flaws, inclusions and other indications shall be reported to GSFC for disposition.

All vendor in-house procedures and specifications shall be submitted to GSFC for review.

5.5 INSPECTIONS

The tank shall be verified by inspection for the following items:

- Workmanship
- Identification
- Dimensions

5.6 LOG BOOK

A log book will be maintained for each tank unit. The target information should be that which is relevant to fracture criticality, contact angle performance, and hydrazine compatibility. Information should include all pressures, test fluids, cleaning fluids, and other items which come into contact with the tank.

5.7 ACCEPTANCE INSPECTIONS, TESTS, AND DESCRIPTIONS

The following sequence of tests and the additional requirements in AFSPCMAN 91-710v3 and in Table 7 shall constitute the acceptance program required for the tank. The acceptance test procedures shall be vendor prepared and submitted for NASA approval.

- Inspection of liner blank prior to forming
- Inspection of formed liner (unmachined) or rough machined liner
- Inspection of machined liner
- Internal penetrant inspection
- Inspection for contact angle
- PMD bubble point
- External penetrant inspection (post weld)
- Radiographic inspection (welds)
- Liner cleanliness
- Liner leak test
- Pre-Installation skirt static load test

After composite wrapping

- Product examination
- Bond line inspection (recording boroscope if design permits)
- Internal volume
- Autofrettage proof pressure
- Internal volume
- External Leakage
- Vibration

- Proof pressure (include length change)
- Skirt and bond proof test
- Bond line inspection (recording boroscope if design permits)
- Radiographic inspection
- Weight
- Dimensional inspection
- Cleanliness

5.7.1 INSPECTION OF THE PRE- AND POST- FORMED LINER

The pre-formed or pre- rough machined liner materials shall be inspected by the vendor per vendor procedure. After rough machining or forming the vendor shall inspect the liner pieces for gross defects such as gouges, scratches, dents, and steps before final machining.

5.7.2 INSPECTION OF MACHINED LINER

The vendor shall inspect the liner pieces for gross defects such as gouges, scratches, dents, and steps before dye penetrant inspection. The vendor shall perform a detailed liner thickness inspection. The liner thickness inspection shall be in sufficient detail to ensure uniformity and adequate process control.

5.7.3 PENETRANT INSPECTION

The inside surfaces of the liner shall be dye penetrant inspected prior to performance of girth welding. The external surfaces of the liner including all welds shall be inspected after all welding and machining steps have been completed on the liner

5.7.4 RADIOGRAPHIC INSPECTION

All external welds on the liner (girth, outlet features, etc) shall be radiographically inspected per the applicable documents.

5.7.5 LINER LEAK TEST

The liner shall be leak tested just prior to wrapping with composite. Low differential pressure with dry He in a vacuum chamber is recommended. The vendor may submit an alternate method for NASA approval.

5.7.6 PRODUCT EXAMINATION

The tank shall be carefully examined for visible defects or any other imperfections that would result in rejection of the tank. This inspection shall include a dimensional verification including outlet tubes.

5.7.7 INTERNAL VOLUME

The internal volume of the tank shall be measured and recorded to within 10 cm^3. The test shall be in compliance with Section 0. Internal volume measurements occur before autofrettage and after post-vibration proof pressure. The volume after autofrettage shall not increase by more than 5%.

5.7.8 PROOF

The tank shall be pressurized to the level stated in Section 0 at a rate not to exceed 0.3447 MPa/30 sec (50 psi/30 sec). As part of the proof test the tank will be taken to minimum internal pressure and held for a minimum of 60 minutes. The proof test is ended with filling the tank with purge gas to a low pressure in preparation for bond line inspection. Upon completion of the proof test, the tank shall be bond line inspected.

5.7.9 EXTERNAL LEAKAGE

The external leakage shall be in compliance with Section 2.15 of this document.

5.7.10 WEIGHT

The tank, clean and dry, shall be weighed and recorded to the nearest 0.1 kg and shall demonstrate compliance with Section 0 of this document.

5.7.11 CLEANLINESS

The tank shall be cleaned, and verified clean to level 100A per IEST-STD- CC1246D as modified by Table 10 below, in accordance with vendor procedures approved by NASA.

The interior of each flight tank shall be cleaned via a vendor supplied, NASA approved procedure to the particulate level in Table 10.

Tank interior surface contamination levels and verification methods will be in accordance with vendor developed levels and procedures approved by NASA.

Table 10. Particulate Cleanliness Specification TBR2

Particle Size Range (μm)	Maximum Allowed per 100 mL
0 to 5	Unlimited
5 to 15	265
15 to 25	78
25 to 50	11*
50 to 100	1*
101 and over	0

*No metal particles allowed

5.8 QUALIFICATION TESTS

The tank design shall be qualified by test and analyses. All previously qualified aspects of the design shall be fully explained and referenced and the qualification test report shall be supplied to GSFC.

The qualification tank will undergo acceptance testing with some modification to order and test levels. The differences are noted in the list below. The qualification tank will be tested to rupture.

The following sequence of tests and the additional requirements in AFSPCMAN 91-710v3 and in Table 11. Verification and Test Matrix shall constitute the qualification program required for the tank. The qualification test procedures shall be vendor prepared and submitted for NASA approval.

- Inspection of liner blank prior to forming
- Inspection of formed liner (unmachined) or rough machined liner
- Inspection of machined liner
- Internal penetrant inspection
- Inspection for contact angle
- PMD bubble point
- External penetrant inspection (post weld)
- Radiographic inspection (welds)
- Liner cleanliness
- Liner leak test
- Pre-Installation skirt static load test

After composite wrapping

- Product examination
- Bond line inspection (recording boroscope if design permits)
- Skirt and bond proof test*
- Internal volume
- Autofrettage proof pressure
- Internal volume
- External Leakage
- Pressure cycling (four times life cycle – one proof cycle, see below)*
- Vibration
- Proof pressure (include length change)
- Skirt and bond proof test
- Bond line inspection (recording boroscope if design permits)

- Radiographic inspection
- Weight
- Dimensional inspection
- Cleanliness
- Burst test (test to rupture)*

* differs from ATP

5.9 RANGE SAFETY COMPLIANCE

The tank shall fully comply with AFSPCMAN 91-710, Volume 3, Chapter 12, "Flight Hardware Pressure Systems and Pressurized Structures" JMR-002A, and JERG-0-001 (See also the 45th Space Wing COPV Letter). The compliance will be documented fully by the vendor and included in the range safety data package.

5.10 VERIFICATION MATRIX

Compliance with the requirements specified in this document shall be in accordance with the Table 11. Verification and Test Matrix. The vendor shall verify compliance with all requirements through analysis, inspection test, or qualification, or more than one method, and document compliance.

Table 11. Verification and Test Matrix

ITEM	DESCRIPTION	SECTION	SIMILARITY	ANALYSIS	INSPECTION	DEVELOPMENT TESTING	ACCEPTANCE TEST	QUALIFICATION TEST
1	Meet the range safety requirements	2.1	✓	✓	✓		✓	✓
2	MDP of no less than 2.758 MPa gauge (400 psig)	2.2		✓				
3	Nominal pressure at 20 C of approximately 2.340 MPa gauge (339.4 psig)	2.3		✓				
4	Proof pressure of no less than 1.25 x MDP, 3.4475 MPa gauge (500 psig)	2.4		✓			✓	
5	Burst pressure > 2.0 x MDP, 5.516 MPa gauge (800 psig)	2.5		✓				✓
6	Minimum pressure capable	2.6		✓			✓	✓
7	Expulsion efficiency shall be greater than 99%	2.7		✓				
8	Operating loaded - temperatures ranging from 2 C to 50 C	2.8		✓				
9	Compatible with fluid and tank temperature non-uniformities	2.8		✓				
10	Maximum fill = 96% of the internal volume at 50°C	2.9		✓				✓

ITEM	DESCRIPTION	SECTION	SIMILARITY	ANALYSIS	INSPECTION	DEVELOPMENT TESTING	ACCEPTANCE TEST	QUALIFICATION TEST
11	Compatible with hydrazine	2.10	✓			✓		
12	10 years ground storage, 10 years with hydrazine, 20°C	2.11	✓	✓		✓		
13	3.5 years for fuel temperature > 45 C for 80% of fueled life	2.11		✓		✓		
14	Nitrogen, Helium, Argon – internal compatible	2.12		✓		✓		
15	No degradation, exposure to water at proof pressure, 1 week	2.12		✓		✓		
16	Metallic membrane shall be constructed of aluminum alloy	2.12			✓			
17	No incompatible impurities via tooling, processes	2.12			✓			
18	Nitrogen, Helium, Argon, water, IPA, leak fluid – external compatible	2.12	✓	✓		✓		
19	Exterior relative humidity up to 100%	2.13	✓	✓			✓	✓
20	Survival temperature and loss of purge	2.14		✓			✓	✓
21	Total leakage rate of no greater than l x l0^{-6} sccs of GHe	2.15		✓			✓	✓
22	Propellant may be offloaded at the launch site once	2.16		✓				
23	Stress rupture requirement	2.17		✓		✓		✓
24	Adequate fatigue life	2.17		✓		✓		

ITEM	DESCRIPTION	SECTION	SIMILARITY	ANALYSIS	INSPECTION	DEVELOPMENT TESTING	ACCEPTANCE TEST	QUALIFICATION TEST
25	Adequate damage-tolerance life (safe-life)	2.17		✓		✓		
26	Liner Leak-before-burst adherence	2.17		✓		✓		✓
27	Skirt, survive static load test	2.17.1.1		✓		✓	✓	✓
28	Skirt, survive a proof test	2.17.1.2		✓			✓	✓
29	Withstand the acceleration loads in Table 2. Load Requirement (Limit Levels)	2.17.2		✓				✓
30	Survive the sinusoidal limit loads given in Table 3. Propellant Tank Sine Specifications	2.17.3		✓			✓	✓
31	Withstand the predicted shock levels given below in Table 4. Propellant Tank Shock Specification (at skirt)	2.17.4		✓			✓	✓
32	Minimum structural resonant frequency (fixed base) shall be above 50 Hz (X direction)	2.17.5		✓			✓	✓
33	Minimum structural resonant frequency (fixed base) shall be above 30 Hz (Y-Z direction)	2.17.5		✓			✓	✓
34	Withstand the random vibration limit levels of Table 5. Propellant Tank Random Vibration Specification - Dry & Table 6. Propellant tank Random Vibration Specification - Full	2.17.6		✓			✓	✓

ITEM	DESCRIPTION	SECTION	SIMILARITY	ANALYSIS	INSPECTION	DEVELOPMENT TESTING	ACCEPTANCE TEST	QUALIFICATION TEST
35	Factors shown in Table 7. Test Factors and Durations shall be used in the testing of the tank	2.17.7		✓			✓	✓
36	Operate after a minimum number of pressure cycles, Table 8. Pressure Cycle Life	2.17.8		✓				✓
37	Ground handling, transportation, acceptance testing, and launch included in the cycle life design and analysis	2.17.8		✓				
38	The PMD shall be constructed of aluminum alloy	0			✓			
39	PMD assembly must have proven hydrazine long term compatibility	0		✓		✓		
40	PMD tooling and processes shall not introduce incompatible impurities into the PMD material	0			✓			
41	PMD surfaces that must wet shall be processed using the Wettable Aluminum 6061 Treatment Process or other approved process	0			✓			
42	Wettability process shall reliably produce surfaces with hydrazine contact angles required by the design after exposure to 20°C hydrazine for 10 years	0	✓		✓	✓		
43	PMD surfaces that must wet shall be maintained such that the contact angle performance is preserved	0			✓			

ITEM	DESCRIPTION	SECTION	SIMILARITY	ANALYSIS	INSPECTION	DEVELOPMENT TESTING	ACCEPTANCE TEST	QUALIFICATION TEST
44	PMD tank shall provide a continuous gas-free flow	0		✓		✓	✓	
45	No structural damage to the PMD from instantaneous peak transient flows	0		✓		✓	✓	
46	PMD operation for fill fractions as low as 50 %	0		✓				
47	Worst case conditions calculated based on a mass range = 2850 kg (6401.1 lb) to 4000 kg (8984 lb)	0		✓				
48	Pressure drop, from the tank to the outlet tube < 0.006895 MPa, (1 psid) at the maximum (non-priming) flow rate	0		✓		✓	✓	✓
49	Contamination of the PMD from tank interior elements	0		✓		✓		
50	Safe loading flow rates for water or hydrazine are specified in the Tank Operational Constraints Document	0		✓		✓		
51	Safe pressurization rates are specified in the Tank Operational Constraints Document	0		✓				
52	Safe offloading flow rates for water or hydrazine are specified in the Tank Operational Constraints Document	0		✓				
53	Safe depressurization rates are specified in the Tank Operational Constraints Document	0		✓		✓		

ITEM	DESCRIPTION	SECTION	SIMILARITY	ANALYSIS	INSPECTION	DEVELOPMENT TESTING	ACCEPTANCE TEST	QUALIFICATION TEST
54	PMD is designed to function properly after tilting within a 5 half angle cone during ground handling.	0		✓				
55	The PMD is designed to function properly while loaded after being exposed to transportation during ground handling.	0		✓				
56	Maximum (non-priming) flow rate = 0.12 kg/sec (0.27 lbm/sec)	0		✓				
57	PMD capable of performing with any combination of thrusters firing	0		✓				
58	PMD capable of performing with any pulse widths > 40 msec	0		✓				
59	PMD supplies propellant used to null 2.0 deg/sec pitch or yaw rates and 0.5 deg/sec roll rates after tip-off; assuming worst case BOL mass and CG	0		✓				
60	0.5 kg (1.1 lbm) of propellant available after exposure to the launch environment and 2 hours of maximum tip-off rate environment	0		✓				
61	0.5 kg is required to be available within 5 minutes of separation from the launch vehicle under the worst case tip off rates	0		✓				
62	5 kg (11 lb) of propellant will be available under the worst case atmospheric drag induced accelerations	0		✓				
63	2.5 kg (5.5 lb) of propellant will be available under the worst case solar	0		✓				

ITEM	DESCRIPTION	SECTION	SIMILARITY	ANALYSIS	INSPECTION	DEVELOPMENT TESTING	ACCEPTANCE TEST	QUALIFICATION TEST
	storm induced drag accelerations							
64	Supply propellant for any of the combinations of thrusters used for drag makeup maneuvers	0		✓				
65	PMD designed such that the forces due to propellant movement associated with any disturbance settles to < 0.005 Nm on the S/C in each axis within 5 minutes of the end of a maneuver	0		✓				
66	PMD will be designed such that coupling between the GMI disturbance and the propellant does not occur	0		✓				
67	The PMD shall be designed such that the priming event causes no degradation to the PMD performance	0		✓				
68	The PMD performance margin shall be a minimum of two	0		✓				
69	The tank nominal capacity is 545 kg of hydrazine for blowdown mode	0		✓	✓			
70	PMD and other internal feature volumes plus residual propellant volume equals 1%	0		✓				
71	The tank shall be capable of supporting a maximum propellant load of a 96% full tank at 50°C	0		✓				✓

ITEM	DESCRIPTION	SECTION	SIMILARITY	ANALYSIS	INSPECTION	DEVELOPMENT TESTING	ACCEPTANCE TEST	QUALIFICATION TEST
72	The tank weight (including the PMD) shall not exceed 45 kg (99 lbs)	0			✓		✓	
73	The tank cylinder shall fit into a cylindrical envelope 1021.6 mm (40.22 in.) in diameter, maximum; the minimum cylinder diameter shall be 978 mm (38.5 in)	0			✓			
74	The skirt shall interface to the inside diameter of a cylinder approximately 1182 mm (46.54 in) in diameter	0			✓			
75	The baseline thickness of the thinnest membrane of the liner shall be 0.762 - 0.889 mm (0.030 - .035 in); minimum 40% of total	0			✓			
76	Composite material outgas < 1.0 percent by weight	0	✓	✓				
77	Composite material collected volatile condensable materials VCM) < 0.1 percent by total weight	0	✓	✓				
78	Skirt installed onto the tank in a separately cured operation from the curing of the wrap	0			✓			
79	The baseline thickness of the thinnest membrane of the overwrap shall be 2.8 mm (0.11 in); minimum 40% of total	0			✓			
80	Design of the internal surfaces of the boss and tank features within the boss shall not trap liquids or liquid born debris such that rinsing, cleaning, or drying operations are hampered	0		✓	✓			

ITEM	DESCRIPTION	SECTION	SIMILARITY	ANALYSIS	INSPECTION	DEVELOPMENT TESTING	ACCEPTANCE TEST	QUALIFICATION TEST
81	Propellant inlet tube physical characteristics	0			✓		✓	
82	Propellant outlet tube physical characteristics	0			✓		✓	
83	Inlet/outlet tubes and fittings per ICD	0			✓		✓	
84	Inlet/outlet tubes and fittings withstand the pressure cycle environment	0		✓				✓
85	Inlet/outlet tubes and fittings analytic proof pressure capability meet requirements of applicable documents	0	✓	✓				✓
86	Inlet/outlet tubes and fittings burst pressure > 11.03 MPa gauge (1600 psig)	0	✓	✓				
87	Skirt interface characteristics	0			✓			
88	Qualify welding process	0	✓					
89	Use A-basis materials	0			✓	✓		
90	Verify contact angle of critical surfaces	0			✓	✓	✓	
91	Fungus inert material	0	✓					
92	Corrosive metals	0	✓					
93	Dissimilar metals	0	✓	✓				

ITEM	DESCRIPTION	SECTION	SIMILARITY	ANALYSIS	INSPECTION	DEVELOPMENT TESTING	ACCEPTANCE TEST	QUALIFICATION TEST
94	Lubricants	0			✓			
95	Interchangeability	0	✓		✓			
96	Identification and marking	0			✓			
97	Wrapping	0			✓			
98	Shipping container	0	✓	✓	✓			
99	Certified witness shall observe the uncovered tanks	0			✓			
100	Protective covers shall comply with AIAA S-081A-2006 (Damage Control)	0			✓			
101	Capable of being stored without intervention for 5 years and with a single intervention for 10 years	0		✓		✓		
102	Mechanical means for supporting the pressure gage	0			✓			
103	Dye penetrant inspected inside and outside surfaces of each dome to Special level	0			✓			
104	Apply any special contact angle enhancing processes after approval of penetrant inspection results	0			✓			
105	Inspection for: workmanship, identification, dimensions	0			✓			

ITEM	DESCRIPTION	SECTION	SIMILARITY	ANALYSIS	INSPECTION	DEVELOPMENT TESTING	ACCEPTANCE TEST	QUALIFICATION TEST
106	A log book will be maintained for each tank unit	0			✓			
107	Inspect pre-formed or pre- rough machined liner materials	0			✓		✓	
108	Inspect post-formed or post- rough machined liner materials	0			✓		✓	
109	Perform a detailed liner thickness inspection	0			✓		✓	
110	Inside surfaces of the liner shall be dye penetrant inspected	0			✓		✓	
111	External welds on the liner radiographically inspected	0			✓		✓	
112	Liner shall be leak tested just prior to wrapping	0			✓		✓	
113	Tank shall be carefully examined for visible defects	0			✓			
114	Inspection shall include a dimensional verification	0			✓		✓	
115	Internal volume of the tank shall be measured and recorded to within 10 cm^3	0			✓		✓	
116	Pressurized to the level stated in Section 0 at a rate not to exceed 0.3447 MPa/30 sec (50 psi/30 sec)	0			✓		✓	
117	Test to minimum internal pressure (0.0 psia) and held hold for a minimum of 60 minutes	0			✓		✓	

ITEM	DESCRIPTION	SECTION	SIMILARITY	ANALYSIS	INSPECTION	DEVELOPMENT TESTING	ACCEPTANCE TEST	QUALIFICATION TEST
118	Bond line inspected	0			✓			
119	Tank weighed and recorded to the nearest 0.1 kg	0			✓			
120	Tank cleaned, and verified clean to level 100A per IEST-STD-CC1246D as modified by Table 10. Particulate Cleanliness Specification TBR	0			✓			